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Experimental Investigation of Machine Foundation Resting on Reinforced Soil Bed: A Review

S. I. Shaikh[1], D. B. Awachat[2], Dr. A. I. Dhatrak[3], S. W. Thakare[4]
Student[1], Scholar[2], Associate Professor [3, 4]
Department of Civil Engineering
Government College of Engineering, Amravati, India
***Corresponding Authors' Email: -** sohelshaikh241297@gmail.com[1], dbawachat@kdk.edu.in[2]*

Abstract

As a result of the machine's moving parts, the machine foundations are constantly subjected to dynamic loads. Because of the repetitive nature of dynamic load leads to increase in foundation soil settlement. The excessive soil settlement can be reduced by lowering the cyclic stresses caused by machine vibrations. The increasing the stiffness of the soil is one method of dealing with cyclic stresses. Soil reinforcement with geosynthetics is one of several techniques for increasing the stiffness of the soil. This review paper discusses the dynamic response of a machine foundation resting on reinforced soil bed. To reduce peak vertical displacement and resonant frequency by using soil reinforcement with geosynthetic material.

Keywords: *Dynamic Force, Geocell, Infill Material, Machine Foundation*

INTRODUCTION

General

The design of machine foundations is considered complex due to the involvement of dynamic loads generated by the machine's moving parts. The stresses produced by the machine elements are repeating in nature, resulting in foundation soil settlement. The settlement caused by cyclic stresses can be reduced by improving the soil's dynamic characteristics. The stiffness and elasticity of the soil are the main properties that influence its behavior. The heavy machinery, moving vehicles, and running trains can all cause harmonic and repetitive vibrations, which cause the supporting foundations to act differently.

As a result, machine foundations should be properly designed to withstand such dynamic loads in order to achieve better workability and durability. Due to the machine's moving elements, the foundations are continuously subjected to dynamic loads. The repeated nature of dynamic load causes excessive foundation soil displacement. By reducing the cyclic loads caused by machine vibrations, severe soil settlement can be prevented. Improving the soil stiffness is one method for reducing cyclic stresses. Geosynthetic reinforcement is one of the methods for increasing the soil stiffness among other techniques. Among the geotechnical engineering field's fastest-growing methods is the use of geosynthetic reinforcement to strengthen the soil below shallow foundations.

Soil Reinforcement Using Geosynthetics Material

Soil reinforcement is a method for increasing the stiffness and strength of soil. Different tension resistant elements, such as geogrid and geocell, are used to enhance soil strength and are positioned within the soil mass so that any potential tensile strain caused by gravity and boundary forces is minimized or suppressed. The applications for reinforced soil technology are numerous. Unreinforced soil performs significantly different than reinforced soil. It is made up of reinforcing strips and earth fill, and it has a high tensile strength capacity. Soil reinforcement, a popular method used in many projects, prevents soil slopes from loosening and enhances the soil's load carrying capacity.

Geocell

Figure 1. Geocell

Geocell as shown in the Figure 1 was used as reinforced material in the experimental study. In this study, a geocell manufactured of a novel polymeric alloy was used. Polyolefin and thermoplastic designing polymerwere the main components of the novel polymeric alloy. The NPA geocells were designed specifically for practical productions and known for their high strength and durability. It consisted of a three-dimensional shaped structure confinement system that greatly increased the load carrying capacity of soft soils, especially in foundation and road surface applications. The interconnected strips serve as the walls of a three-dimensional, flexible cellular structure into which indicated infill materials were positioned and compressed. By providing confinement through tensile reinforcement, this results in a free-draining system that stops mass movements and maintains the infill materials in place. The structural and functional behaviour of soils and aggregate infill materials is improved by cellular confinement systems.

Quarry Dust

Quarry dust as shown in the Figure 2 is the infill material to be used in the geocell pocket. Quarry dust is a natural outcome of the crushing process that produced a concentrated material suitable for use as aggregates in concrete, particularly fine aggregates.Quarry dust is the dust produced when rock is crushed into various sizes during quarrying activities.

Figure 2. Quarry Dust

LITERATURE REVIEW

The following were some experimental and numerical investigations carried out on machine foundation resting on reinforced soil by various researchers.

Ghosh et.al (2012) presented a study of the difference in dynamic behaviour between two adjacent square or rectangle-shaped machine foundations on a layer of soil and one isolated foundation. Modeling was done using the explicit finite difference code18 FLAC3D. On the surface of the active foundation, one of the interacting foundations, an oscillatory dynamic loading with varying amplitude was applied. The investigation concentrated on how motion of an active foundation in a layered soil medium affected nearby passive foundations. Both foundations' uniform embedment ratios (D/B) were 0.5, where B and D stood for the foundations' respective embedment breadth and depth. The analysis was performed to assess the interference effect of adjacent foundations under dynamic conditions in terms of settlement and the distribution of normal and shear stress at the base of active and passive foundations. The analysis was carried out to determine the interference effect of closely placed foundations under dynamic condition in terms of the settlement as well as the normal and shear stress distribution at the base of both active and passive foundations. Figure 3 represents the problem definition under sinusoidal dynamic loading and Figure 4 shows Failure domain and mesh generation in FLAC 3D.

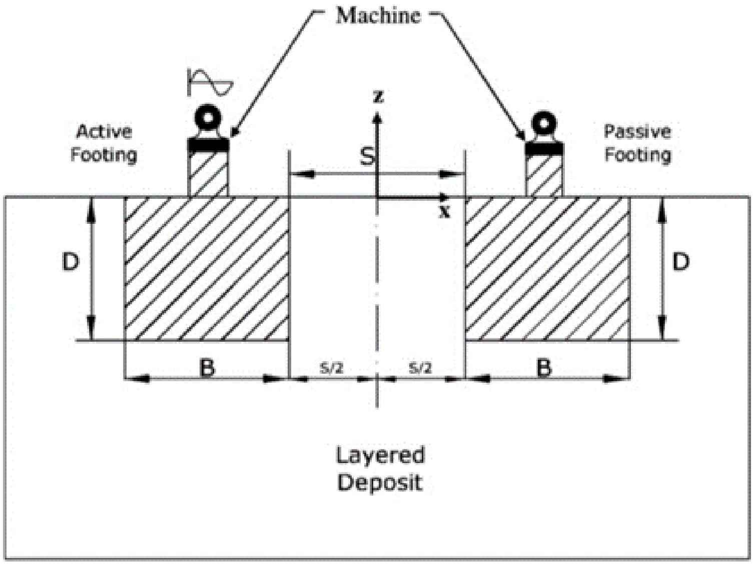


Figure 3: Problem definition under sinusoidal dynamic loading

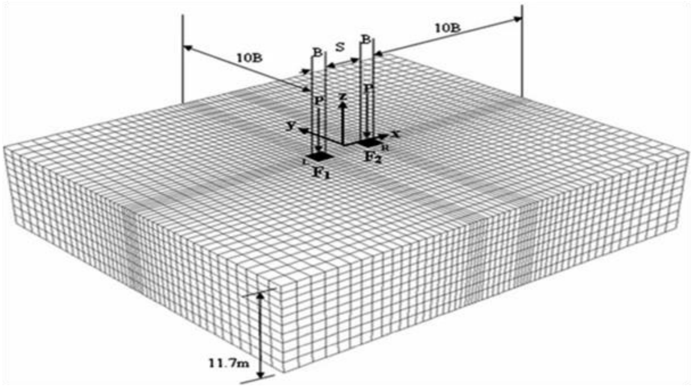


Figure 4: Failure domain and mesh generation in FLAC 3D

Under the static working load condition, the settlement and the average vertical normal stress (rzz) obtained below the isolated and interfering foundations are shown in Tables 1 and 2.

Table1: Settlement of isolated and interfering foundations under static working load condition

S/B	Settlement(mm)		
	Square footing	Rectangular footing	
	L/B =1	L/B =2	L/B =3
Isolated	21.4	33.7	37.8
1	26.5	34.0	39.4
3	24.9	32.7	36.8
5	23.2	32.8	36.9

Table 2: Average vertical stress (σzz) at the base of isolated and interfering foundations under static working load condition

S/B	σzz(N/m^2)		
	Square footing	Rectangular footing	
	L/B =1	L/B =2	L/B =3
Isolated	4.95×10^4	6.43×10^4	6.82×10^4
1	5.41×10^4	6.20×10^4	6.71×10^4
3	5.39×10^4	6.23×10^4	6.65×10^4
5	5.15×10^4	6.29×10^4	6.68×10^4

Based on the Numerical Analysis the following conclusions were drawn.

1. The dynamic settlement of both active and passive foundations decreases with increase in S/B ratio, but increases with increase in L/B ratio.
2. In presence of the dynamic excitation, the magnitude of the vertical normal (rzz) and shear stresses developed at the base of the interfering foundations increases with increase in L/B ratio, but decreases with increase in S/B.

Abhijeet Swain et.al (2015) presented results of experimental evaluation of the dynamic interaction effect of square foundations that are closely spaced under mechanical vibration. A number of experiments were carried out in the field under dynamic conditions, as well as extensive research on the isolated and interacted footing response resting on the local soil in Kanpur, India. The dynamic interaction of an adjacent footing assemblies with a square shapes were investigated by excited vertical dynamic force on one footing (active footing), where another footing (passive footing) was only loaded with dead load. Both footings, which were placed at different clear spacings, performed as the active footing was excited with varying levels of dynamic stress (S).The observations were assembled and displayed as the frequency fluctuation of displacement amplitude. The transmission ratios, which predicted the influence of dynamic excitation of the active footing on the passive footing, were calculated and plotted for the interaction concrete foundations in relation to the frequency ratio. A variable speed 3HP DC motor was used to operate the mechanical oscillator to run at different frequency ranging from 120 rpm – 3000 rpm. The DC motor was placed and clamped over the oscillator and their shafts were connected with a V-belt as shown in Figure5.

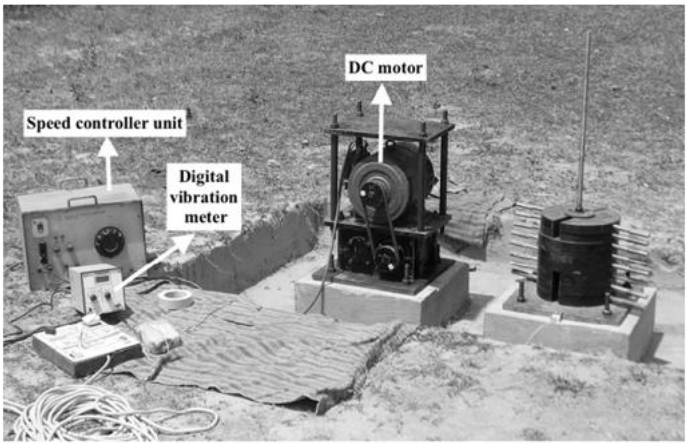
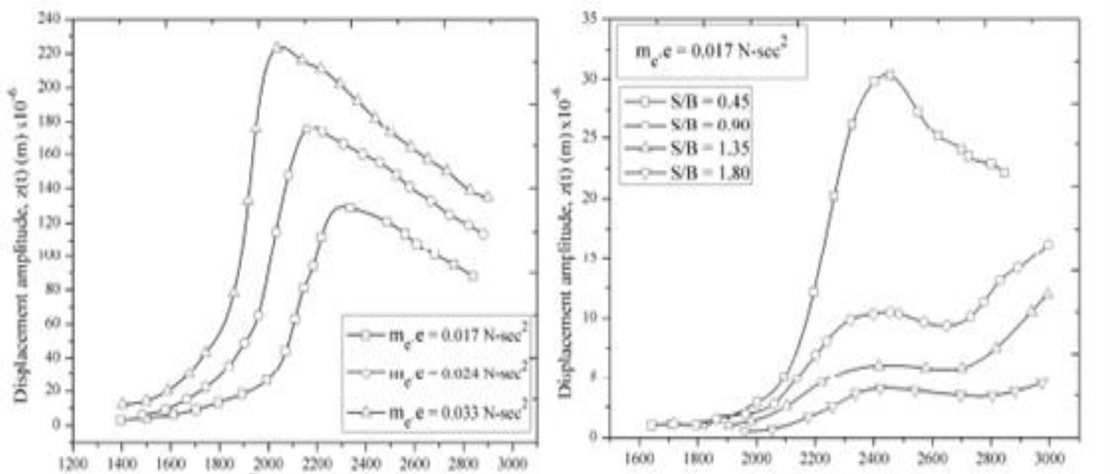


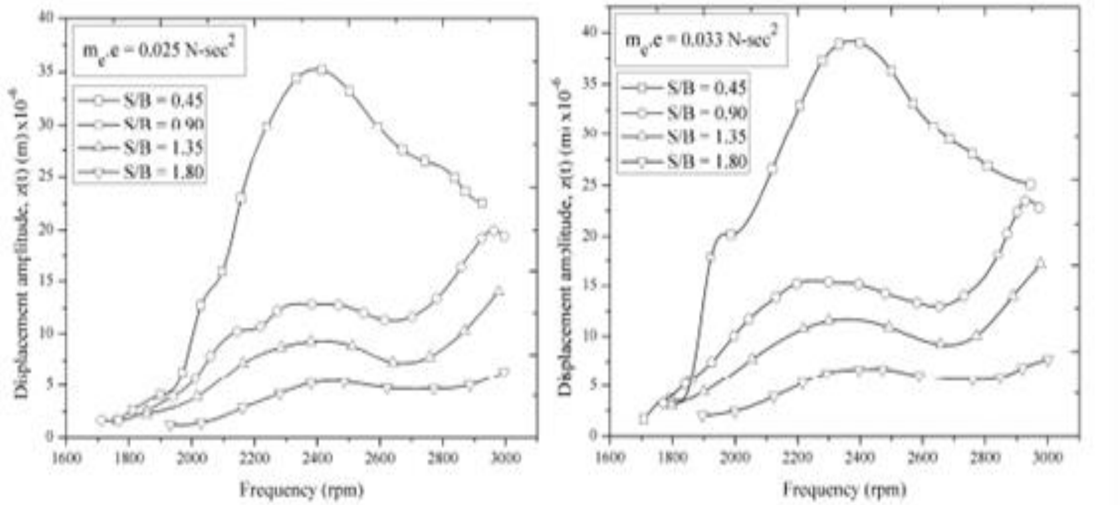
Figure 5: Photographic view of the experimental setup

Several tests were conducted on the interfering footings F1 and F2 in four basic combinations (F1-F1, F1-F2, F2-F1 and F2-F2) to explore the dynamic interaction between two nearby footings. The variations of the displacement amplitude with the frequency for both active and passive footings are shown in Figures 6 and 7.



(a) Active footing response for $I_{21}S_{0.45}E_{16}$, $I_{21}S_{0.90}E_{16}$, $I_{21}S_{1.35}E_{16}$, $I_{21}S_{1.80}E_{16}$, $I_{21}S_{0.45}E_{24}$, $I_{21}S_{0.90}E_{24}$, $I_{21}S_{1.35}E_{24}$, $I_{21}S_{1.80}E_{24}$, $I_{21}S_{0.45}E_{32}$, $I_{21}S_{0.90}E_{32}$, $I_{21}S_{1.35}E_{32}$ and $I_{21}S_{1.80}E_{32}$.

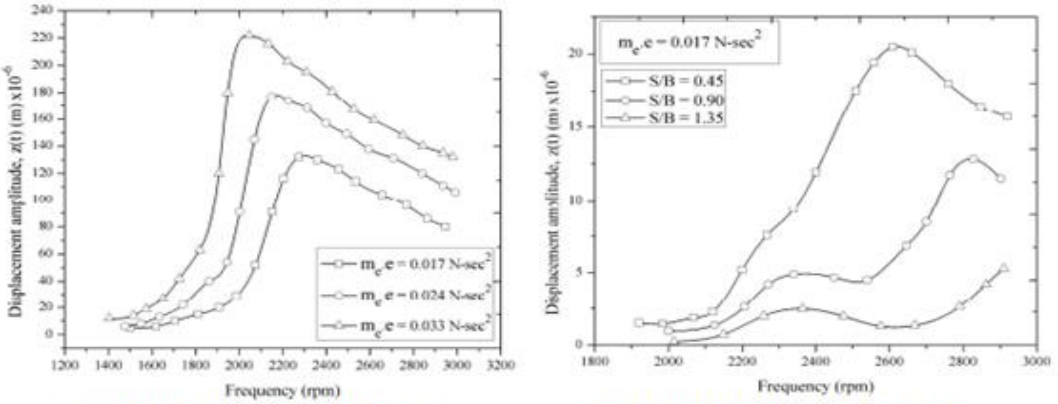
(b) Passive footing response for $I_{21}S_{0.45}E_{16}$, $I_{21}S_{0.90}E_{16}$, $I_{21}S_{1.35}E_{16}$ and $I_{21}S_{1.80}E_{16}$



(c) Passive footing response for $I_{21}S_{0.45}E_{24}$, $I_{21}S_{0.90}E_{24}$, $I_{21}S_{1.35}E_{24}$ and $I_{21}S_{1.80}E_{24}$

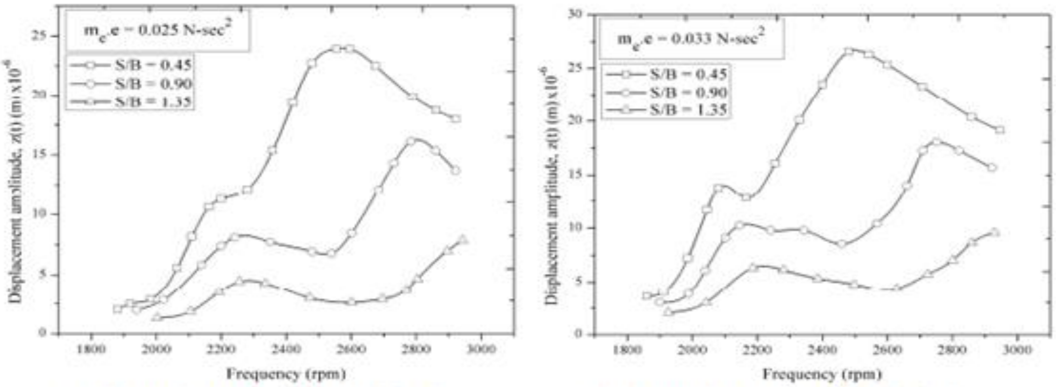
(d) Passive footing response for $I_{21}S_{0.45}E_{32}$, $I_{21}S_{0.90}E_{32}$, $I_{21}S_{1.35}E_{32}$ and $I_{21}S_{1.80}E_{32}$

Figure 6: Dynamic response due to interaction between F1 (active) and F2 (passive) footings



(a) Active footing response for $I_{22}S_{0.45}E_{16}$, $I_{22}S_{0.90}E_{16}$, $I_{22}S_{1.35}E_{16}$, $I_{22}S_{0.45}E_{24}$, $I_{22}S_{0.90}E_{24}$, $I_{22}S_{1.35}E_{24}$, $I_{22}S_{0.45}E_{32}$, $I_{22}S_{0.90}E_{32}$ and $I_{22}S_{1.35}E_{32}$

(b) Passive footing response for $I_{22}S_{0.45}E_{16}$, $I_{22}S_{0.90}E_{16}$ and $I_{22}S_{1.35}E_{16}$



(c) Passive footing response for $I_{22}S_{0.45}E_{24}$, $I_{22}S_{0.90}E_{24}$ and $I_{22}S_{1.35}E_{24}$

(d) Passive footing response for $I_{22}S_{0.45}E_{32}$, $I_{22}S_{0.90}E_{32}$ and $I_{22}S_{1.35}E_{32}$

Figure 7: Dynamic response due to interaction between F1 (active) and F2 (passive) footings

Based on the experimental investigations the following conclusion was drawn. It was observed that the passive footings undergo resonance due to the dynamic excitation on the active footing, which occur, however, with a phase lag from the resonant frequency of the active footing.

M.V.S. Sreedharet.al (2016) conducted model block resonance experiment was to understand better the response of a geosynthetic reinforced soil bed positioned beneath a model machine foundation. A group of laboratory model blocks Vibration experiments were carried out on a test bed with and without geosynthetic reinforcement. A non-woven geotextile and a bi-axial geogrid were used to reinforce the test bed. The effect of these reinforcement elements on the dynamic properties of the test bed, particularly the resonance frequency and peak amplitude, was investigated. It was observed that the resonance frequency had changed and that the peak amplitude had declined substantially. As a result, it was determined that the use of geosynthetics beneath the machine foundations assisted in adjusting the frequency ratio as well as reducing the peak amplitude, that were the two main needs of machine foundation design. A test pit of size 1.80 m x 1.60 m x 1.20 m was prepared for the test block of 0.60 m x 0.50 m x 0.40 m, as shown in Figure 8.As it can be seen from Figure 9 the nature of peak vertical displacement versus Frequency curve was typical indicating the resonance distinctly. The peak displacement at resonance was found to show a definite decrease when reinforced.

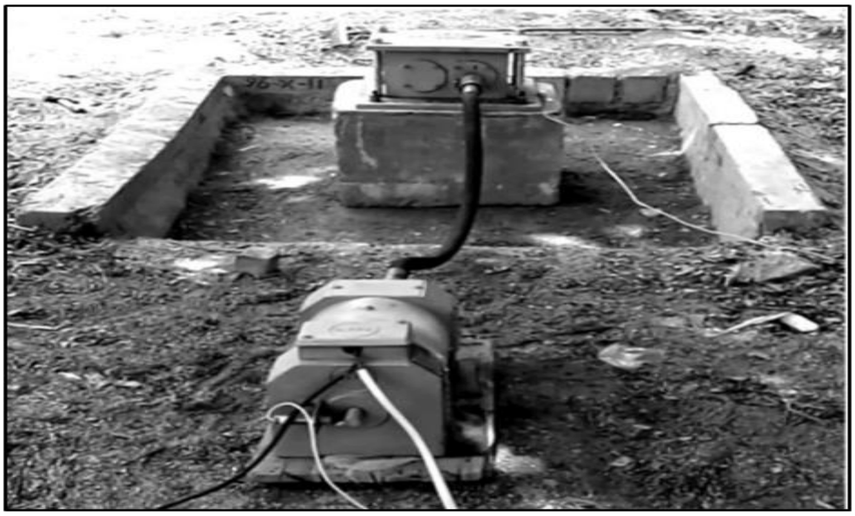


Figure 8: A view of the experimental setup

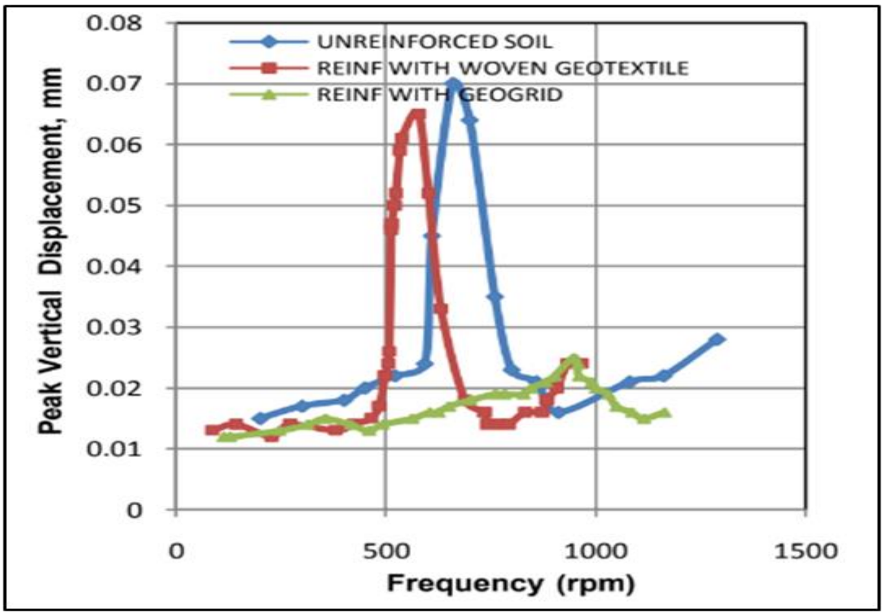


Figure 9: Peak Vertical Displacement (vs) Frequency plot

Table 3: Summary of results

Test Condition	Peak displacement at Resonance		Magnification Factor at resonance	
	(mm)	% Drop	Value	% Drop
Soil	0.07	0.00	7.34	0.00
Soil + Woven Geotextile	0.065	7.10	6.58	10.40
Soil + Biaxial Geogrid	0.025	64.30	3.84	47.70

In Table3, the magnification factor is dropped to an extent of 47.70 % when reinforced, signifying the efficacy of reinforcement. The relatively better performance of geogrid over geotextile was attributed to the higher modulus and better interaction.

Based on the experimental investigations the following conclusions were drawn.

1. The geosynthetic reinforcement provided beneath the model machine foundation indicated a definite improvement in the response of foundation soil.

2. Considerable drop was observed in the Peak Vertical displacement and the Peak Magnification factor at resonant condition. This substantiates the potential of Geosynthetics in improvement of ground beneath machine foundations.

3. A shift in resonant frequency was observed signifying the role of geosynthetics in tuning of machine foundations.

4. The relative efficacy of improvement by the geosynthetics was considered to be dependent on the in-isolation modulus and interaction parameters.

H. Venkateswarlu et.al (2017) investigated geosynthetics-enhanced soil beds supporting model machine foundations: Results on the field testing and analytical simulations. On a firm concrete base supported by various reinforcing soil conditions, several lateral mode block vibration tests are conducted. Evaluations were done for the conditions of no reinforcement, one layer of geogrid reinforcement, two layers of geogrid reinforcement, and geocell reinforcement. The tests are carried out utilizing a Lazen type mechanical oscillator at six distinct dynamic force ranges a total of 38 field tests are carried out.

The dynamic behavior is investigated in terms of resonant frequency reduction, peak particle velocity (PPV), and enhancement in soil dynamic characteristics. The existence of geosynthetics considerably lowered the displacement amplitude of vibration, according to the experimental results. When compared with the other conditions, the existence of geocell reinforcement results in the greatest reduction. In comparison to the unreinforced state, the addition of geocell reinforcement decrease resonant frequency by 61% while increasing the soil system's natural frequency by 1.38 times.

Additionally, it was found that the geocell reinforcement decreased the PPV by 48% at 0.5 meters from the side of the foundation. The foundation bed's elastic uniform deformation is 91% better when geocell reinforcement is used. The schematic representation of the block vibration test setup is shown in Figure 10.

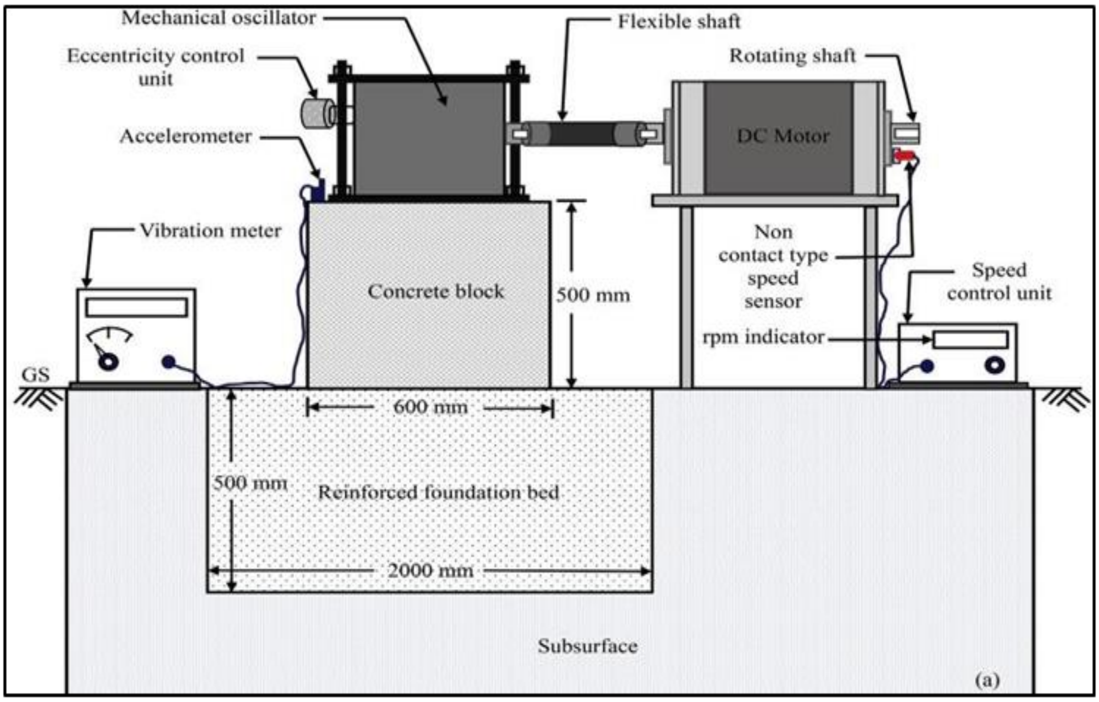


Figure 10: A Block vibration test setup

The variation in dynamic force with the change in frequency and eccentricity angle is shown in Figure 11. Figure 12 shows the dynamic response of a geogrid reinforced condition.

From the Figure 12, it is observed that the rate of reduction of displacement amplitude is high as compared to the single geogrid reinforced condition. Provision of second layer has also enhanced the natural frequency of the system significantly.

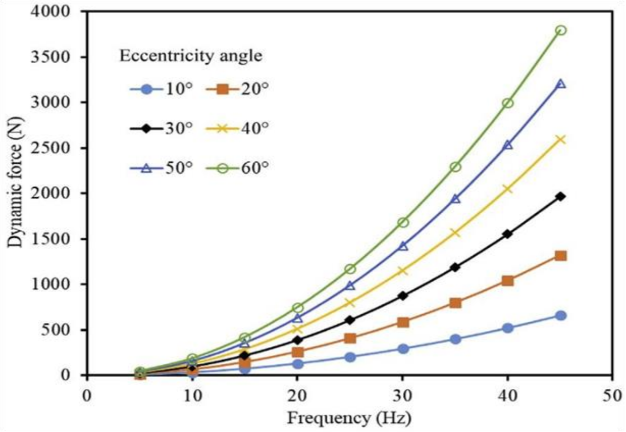


Figure 11: Variation of dynamic force with increase in eccentricity angle and frequency of the excitation

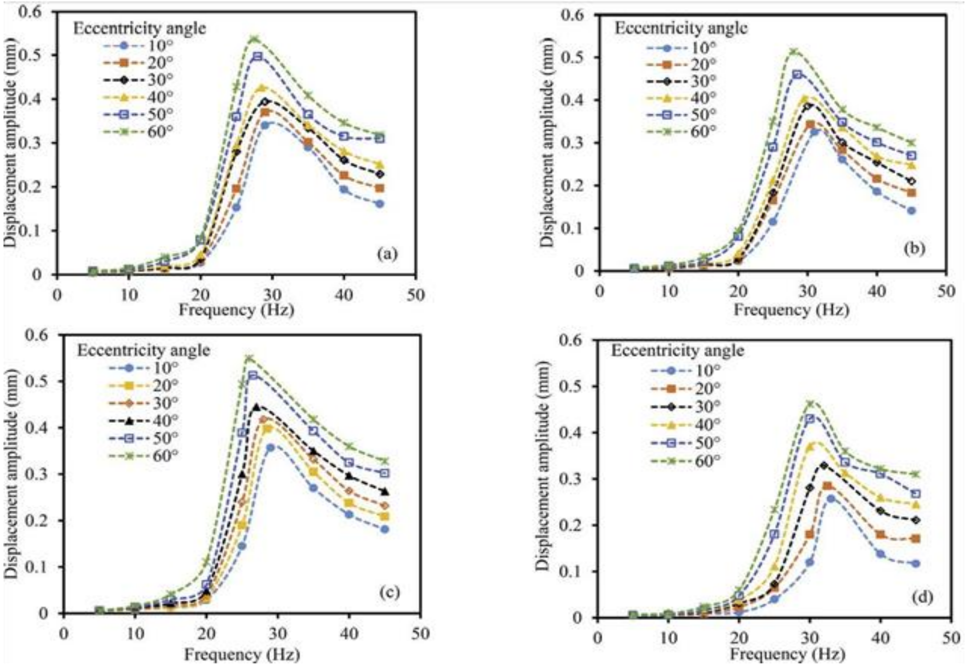


Figure 12: Displacement amplitude versus frequency response for geogrid reinforced condition: (a) geogrid @ 0.15B; (b) geogrid @ 0.3B; (c) geogrid @ 0.45B; (d) reinforced with two layers of geogrid

Based on the experimental investigations the following conclusions were drawn.

1. The performance of geosynthetics reinforced soil was found to be effective in controlling the machine vibrations.

2. The optimum depth of placement of geogrid was found at 0.3B in the case of geogrid reinforced condition.

3. The performance of geocell was found more effective than other conditions considered in this study.

R. Zakeriet al.(2020) Studied the efficiency of employing rubber sheets to modify the dynamic response of a concrete machine foundation model of size 400 x 400 mm by conducting a series of steady-state vertical vibration tests. Rubber is a low-cost energy dissipater material having high resistance to erosion which can be used in a form of sheets and simply placed beneath foundations. Granular soil passing through the 20 mm sieve with a specific gravity of 2.66 was chosen as the test soil material. Rubber sheets 500 × 500 mm in plan and of four different thicknesses (6, 12, 18 and 24 mm) were used. Their width was chosen to be 100 mm larger than the foundation. The density of the rubber sheet was determined to be about 16.7 kN/m3 . Figure 13 shows the rubber sheet used in experimental investigations.

Figure 13: The rubber sheet

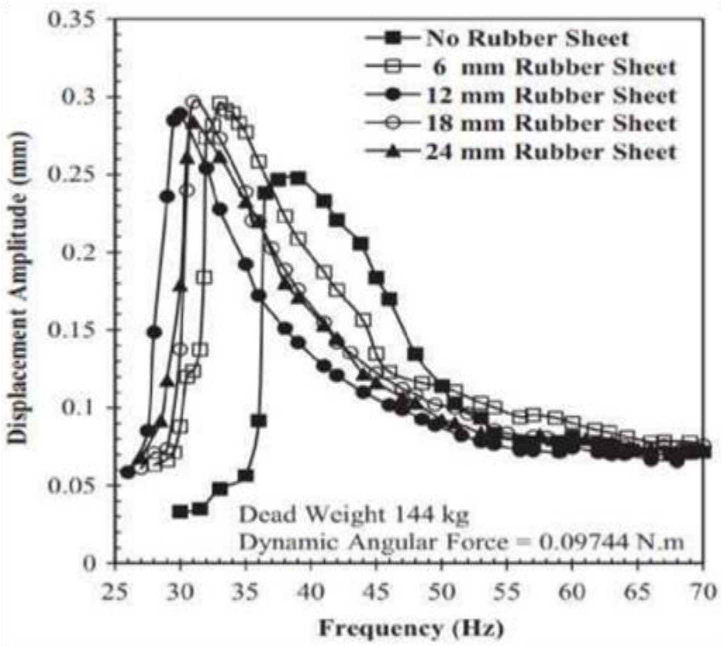


Figure 14: Variation of vertical displacement versus frequency for different rubber sheet thickness

The effect of rubber sheet thickness on the dynamic response of the machine foundation model, tests were conducted using rubber sheets 500 x 500 mm in plan and with thicknesses of 6, 12, 18 and 24 mm immediately beneath the foundation. In these tests, the dynamic angular force of 0.0956 Nm (D1) and dead weight of 144 kg (W1) were employed. Results are presented as a variation of vertical displacement versus frequency of vibration, as shown in Figure 14.

Based on the experimental investigations the following conclusions were drawn.

1. The use of a rubber sheet as a means of enhancing the dynamic response of a machine foundation model subjected to a series of steady-state vibration tests.

2. It was found that the resonant frequency and dynamic amplitude both reduce as the amount of soil between the foundation and a rigid layer increase.

CONCLUSIONS

From the brief review it can be concluded that many studies have been carried out experimentally and analytically to investigate, the effect of soil, foundation embedded, foundation types, interference with passive foundation, frequency of machine vibration on machine foundation response but there is need to study geosynthetics material support to the machine foundations. So, in future research work should be focused on the study of the performance of geosynthetics material (geotextile, geogrid and geocell) and naturally available materials such as quarry dust as filler material in soil bed.

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